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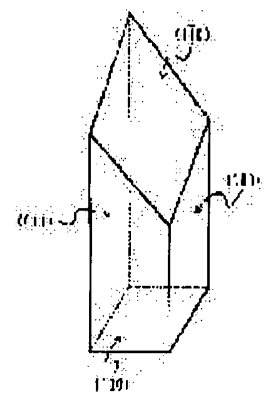
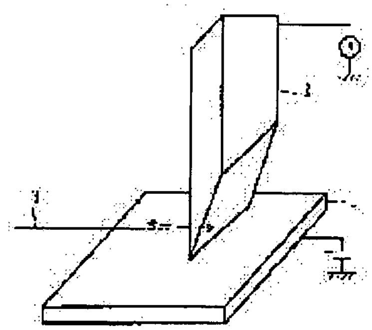
(71)Applicant : FUJITSU LTD
(72)Inventor : KODAMA HIROKI
UZUMAKI TAKUYA

(54) SPIN POLARIZATION SCANNING TYPE TUNNELING MICROSCOPE, ITS PROBE, AND MAGNETIZATION INFORMATION EVALUATION METHOD





(57)Abstract:
PROBLEM TO BE SOLVED: To restrain external disturbance and enable measurement of high precision, by making, the vertex of conical surfaces of a polygonal pyramid formed on semiconductor material in which spin-polarized electrons are excited by laser light irradiation, a tip, and arranging one conical surface out of conical surfaces defining the tip so as to be vertical to the surface of an object to be estimated.
SOLUTION: A probe 2 formed of GaAs single crystal makes the vertex of a triangular pyramid a tip which pyramid is formed of three conical surfaces, e.g. a (100) face, a (011) face and a (1-11) face. The (100) face is perpendicular to the (011) face. The (011) face and the (1-10) face make an angle of 60°. The (1-10) face and the (100) face make an angle of 45°. The probe 2 is made to face the magnetic surface of magnetic material 1, and the (100) face and the (011) face are made vertical to the magnetic surface. A laser light is made to enter vertically to the (100) face, and make the probe 2 excite spin-polarized elections. By measuring the magnitude of a tunneling current flowing in the part between the tip of the probe 2 and the magnetic material 1, the direction of magnetization of the magnetic material 1 is evaluated.

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PRIOR ART

[Description of the Prior Art] In recent years, the recording density of magnetic-recording media, such as a hard disk for external memories of a computer, is improving remarkably. The magnetic-force microscope, the BITTA method, etc. are learned as the technique of evaluating the magnetic information. If recording density will improve further from now on and one magnetic domain becomes detailed, it will be predicted by these evaluation methods that it becomes evaluation difficulty.
[0003] The spin polarization scanning tunneling microscope is proposed as new equipment by which the magnetic information on a magnetic front face that it has a detailed magnetic domain is evaluated. A spin polarization scanning tunneling microscope is equipment which the nose of cam of the probe which has the conduction electron which carried out spin polarization is made to counter at a minute interval on the surface of a magnetic material, passes a tunnel current between a probe and a magnetic material, and evaluates magnetic information by the size of a tunnel current.
[0004] The probe which emits the electron which carried out spin polarization is needed for this spin polarization scanning tunneling microscope. Since it approaches extremely and is arranged to a sample, as for this probe, forming by non-magnetic material is desirable in order not to change the magnetization information on a sample. GaAs is known as a material which may emit the electron which carried out spin polarization by non-magnetic material.
[0005] G. The probe of GaAs produced by NYUNESU and others (G.Nunes) using the cleavage method is reported. This probe carries out the cleavage of the GaAs substrate of a field (100) by the field (100) and the 2nd page which makes the angle of 90 degrees, and uses the intersection of a field (100) and two cleavage planes as a nose of cam.
[0006] By irradiating the circle deviation laser beam of the wavelength which is equivalent to the band gap of GaAs at the probe of this GaAs, the electron of a valence band can be excited and the conduction electron which carried out spin polarization can be obtained. The degree of polarization of conduction electron is 50%, and the direction of polarization is parallel to the optical axis of an irradiation laser beam. The sense of polarization is decided by the revolution direction of a circle deviation laser beam.
[0007] This probe is made to counter a magnetic front face, and if the laser beam which has an optical axis parallel to a magnetic front face is irradiated at a probe, the conduction electron which has parallel spin polarization to a magnetic front face in a probe will be excited. The size of a tunnel current changes with the relation between the sense of magnetization of a magnetic front face, and the sense of the spin polarization of the electron in a probe. Therefore, the information about the sense of magnetization of a magnetic front face can be acquired by measuring the size of a tunnel current.
[0008] When the magnetic front face is magnetized in parallel to the front face, the optical axis of a laser beam is made parallel to a magnetic front face.

[Translation done.]

TECHNICAL FIELD

[The technical field to which invention belongs] this invention relates to a spin polarization scanning tunneling microscope, its probe, and the magnetization information-evaluation method. A spin polarization scanning tunneling microscope can observe the situation of magnetization of a magnetic material, and has high resolution.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
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[0002]
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[0003] The spin polarization scanning tunneling microscope is proposed as new equipment by which the magnetic information on a magnetic front face that it has a detailed magnetic domain is evaluated. A spin polarization scanning tunneling microscope is equipment which the nose of cam of the probe which has the conduction electron which carried out spin polarization is made to counter at a minute interval on the surface of a magnetic material, passes a tunnel current between a probe and a magnetic material, and evaluates magnetic information by the size of a tunnel current.
[0004] The probe which emits the electron which carried out spin polarization is needed for this spin polarization scanning tunneling microscope. Since it approaches extremely and is arranged to a sample, as for this probe, forming by non-magnetic material is desirable in order not to change the magnetization information on a sample. GaAs is known as a material which may emit the electron which carried out spin polarization by non-magnetic material.
[0005] G. The probe of GaAs produced by NYUNESU and others (G.Nunes) using the cleavage method is reported. This probe carries out the cleavage of the GaAs substrate of a field (100) by the field (100) and the 2nd page which makes the angle of 90 degrees, and uses the intersection of a field (100) and two cleavage planes as a nose of cam.
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[0007] This probe is made to counter a magnetic front face, and if the laser beam which has an optical axis parallel to a magnetic front face is irradiated at a probe, the conduction electron which has parallel spin polarization to a magnetic front face in a probe will be excited. The size of a tunnel current changes with the relation between the sense of magnetization of a magnetic front face, and the sense of the spin polarization of the electron in a probe. Therefore, the information about the sense of magnetization of a magnetic front face can be acquired by measuring the size of a tunnel current.
[0008] When the magnetic front face is magnetized in parallel to the front face, the optical axis of a laser beam is made parallel to a magnetic front face.
[0009]

[Problem(s) to be Solved by the Invention] G. When NYUNESU's and others probe is made to counter a magnetic front face, all the three conical surfaces that demarcate the nose of cam become slanting to a magnetic front face, and it will turn to a magnetic front-face side. Therefore, if the laser beam which has an optical axis parallel to a magnetic front face is irradiated at a probe, the reflected light will carry out incidence to a magnetic front face. The reflected light which carried out incidence to the magnetic front face serves as disturbance, and is considered to have a bad influence on a magnetization measure of information.

[0010] The purpose of this invention is suppressing the disturbance given to the magnetic front face which should be measured as much as possible, and offering the evaluation method of the spin polarization scanning tunneling microscope in which highly precise measurement is possible, its probe, and the magnetization information on a magnetic front face.

[0011]

[Means for Solving the Problem] According to one viewpoint of this invention, it is formed of the semiconductor material by which the electron which carried out spin polarization by irradiation of a laser beam is excited. Use the peak of the conical surface of multiple weight as a nose of cam, and this nose of cam is made to counter the virtual flat surface which has set a certain interval. When the one conical surface has been perpendicularly arranged to this virtual flat surface among two or more conical surfaces which demarcate this nose of cam, the probe for spin polarization scanning tunneling microscopes which approaches the aforementioned virtual flat surface most only in the aforementioned nose of cam is offered.

[0012] The one conical surface measures among the conical surfaces which demarcate a nose of cam by arranging so that it may become perpendicular to the front face of an evaluation object. If incidence of the laser beam which has an optical axis parallel to the front face of an evaluation object is carried out to the conical surface perpendicularly arranged to the front face of an evaluation object, the optical axis of the reflected light will also become parallel to the front face of an evaluation object. For this reason, it becomes impossible for the reflected light to carry out incidence to an evaluation object, and it can avoid the influence on measurement by the incidence of the reflected light.

[0013] According to other viewpoints of this invention, it is formed of the semiconductor material by which the electron which carried out spin polarization by irradiation of a laser beam is excited. Use the peak of the conical surface of multiple weight as a nose of cam, and this nose of cam is made to counter the virtual flat surface which has set a certain interval. The probe which approaches the aforementioned virtual flat surface most only in the aforementioned nose of cam when the one conical surface has been perpendicularly arranged to this virtual flat surface among two or more conical surfaces which demarcate this nose of cam, The sample maintenance base which has the flat sample maintenance side which sets the interval which exists at the nose of cam of the aforementioned probe, and counters, The probe maintenance means [to hold the aforementioned probe so that the one conical surface of the aforementioned probe may become perpendicular to the aforementioned sample maintenance side], and aforementioned one conical surface of the aforementioned probe is provided with the spin polarization scanning tunneling microscope which has a laser beam study system for irradiating the laser beam which has an optical axis parallel to the aforementioned sample maintenance side.

[0014] The optical axis of the reflected light of the laser beam which carried out incidence to the probe becomes parallel to a sample maintenance side. For this reason, it becomes impossible for the reflected light to carry out incidence to the evaluation object laid in the sample maintenance side, and it can avoid the influence on measurement by the incidence of the reflected light.

[0015] According to other viewpoints of this invention, it is formed of the semiconductor material by which the electron which carried out spin polarization by irradiation of a laser beam is excited. Use the peak of the conical surface of multiple weight as a nose of cam, and this nose of cam is made to counter the virtual flat surface which has set a certain interval. When the one conical surface has been perpendicularly arranged to this virtual flat surface among two or more conical surfaces which demarcate this nose of cam The process arranged so that the one conical surface may become perpendicular to this measured front face among the conical surfaces which the probe which approaches the aforementioned virtual flat surface most only in the aforementioned nose of cam is made to counter this measured front face of the sample which has a flat measured front face, and demarcate the nose of

cam of this probe, The one aforementioned conical surface is provided with the magnetization information-evaluation method of a magnetic front face of having this probe and the process which detects the tunnel current which flows between samples, by impressing direct current voltage between the process which irradiates the laser beam which has an optical axis parallel to the aforementioned measured front face, and the aforementioned probe and the aforementioned sample.

[0016] Since the optical axis of the reflected light of the laser beam which carried out incidence to the probe is parallel to a measured front face, the reflected light does not carry out incidence to a measured front face. For this reason, the influence on measurement by the reflected light is avoidable.

[0017]

[Embodiments of the Invention] Drawing 1 (A) and (B) show the perspective diagram of the probe for spin polarization scanning tunneling microscopes by the example of this invention. It is formed with both GaAs single crystals.

[0018] The probe shown in drawing 1 (A) uses as a nose of cam the vertex of the triangular pyramid which makes a field (100), a field (011), and (1-10) a field the three conical surfaces. (100) A field and a field (011) intersect perpendicularly, a field (011) and a field (1-10) cross at 60 degrees, and a field (1-10) and a field (100) cross at 45 degrees.

[0019] This probe can carry out the cleavage of the GaAs substrate which the field (100) or (011) the field expressed, and can produce it. First, the cleavage of the GaAs substrate is carried out in the [110] directions. Let the GaAs piece by which placed the glass plate in parallel with the direction which carried out the cleavage, and carried out the cleavage further with scribing, and the cleavage was carried out in the field (1-10) be a probe.

[0020] The probe shown in drawing 1 (B) uses as a nose of cam the vertex of the triangular pyramid which makes a field (001), a field (1-10), and (0-11) a field the three conical surfaces. This probe is producible by carrying out the cleavage of the GaAs substrate which the field (001) or (1-10) the field expressed. The configuration of a probe shown in drawing 1 (B) is the same as that of the probe shown in drawing 1 (A), and the field (001) of the probe of drawing 1 (B), a field (1-10), and (0-11) a field are equivalent to the field (100) of the probe of drawing 1 (A), a field (011), and (1-10) a field, respectively.

[0021] Next, with reference to drawing 2 , how to detect the magnetization information on the front face of a magnetic material using the probe shown in drawing 1 (A) is explained. In addition, it is the same when using the probe shown in drawing 1 (B).

[0022] The interval of about several angstroms is set on the magnetic front face of the magnetic material 1 which has a flat front face, and the nose of cam of a probe 2 is made to counter it. At this time, a probe 2 is arranged so that a field (100) and (011) a field may become perpendicular to the magnetic front face of a magnetic material 1. For example, a field (100) is made to carry out incidence of the laser beam 3 which has an optical axis perpendicular to a magnetic front face. A laser beam 3 is a circle deviation laser beam which has the wavelength equivalent to the band gap of GaAs.

[0023] A part of laser beam 3 is absorbed by the probe of GaAs, and it excites the electron which carried out spin polarization. The direction of polarization of this electron is parallel to the optical axis of a laser beam 3, and the sense is decided by the revolution direction of a laser beam 3. Right voltage is impressed to the magnetic material 1 to the probe 2, and a tunnel current flows between the nose of cam of a probe 2, and a magnetic material 1.

[0024] The size of a tunnel current is decided by the relative relation of the sense of electronic polarization and the sense of magnetization of a magnetic material 1 which carried out spin polarization in the probe 2. For this reason, the sense of magnetization of a magnetic material 1 can be evaluated by measuring the size of a tunnel current. Moreover, the situation of a distribution of the magnetic domain of a magnetic front face can be evaluated by scanning a probe 2 about the inside of a magnetic front face.

[0025] A part of laser beam 3 is reflected according to the field (100) of a probe 2. (100) Since the field is perpendicularly arranged to the magnetic front face, the optical axis of the reflected light also becomes parallel to a magnetic front face, and the reflected light does not carry out incidence to a magnetic material 1. For this reason, the bad influence by the reflected light is eliminated and the stable measurement is attained.

[0026] In addition, although it is desirable that the field a laser beam carries out [the field] incidence is

made perpendicular to a magnetic front face, as long as the reflected light is the inclination of the grade which does not carry out incidence to a magnetic front face substantially, the field of a laser beam which carries out incidence may lean minutely to the normal of a magnetic front face. Here, although the reflected light carries out incidence to a magnetic material when the reflected light passes outside the periphery of a magnetic material and, since the probe index is distant from the station, the case "where incidence is not substantially carried out to a magnetic front face" means a case so that observation may not be affected.

[0027] Although the above-mentioned example explained the probe which used GaAs, you may use the semiconductor material by which the electron which carried out spin polarization by irradiation of a laser beam in addition to GaAs is excited. In this case, the peak of the conical surface of multiple weight is used as a nose of cam, this nose of cam is made to counter the virtual flat surface which has set a certain interval, and when the one conical surface has been perpendicularly arranged to a virtual flat surface among two or more conical surfaces which demarcate a nose of cam, it considers as a configuration which approaches the aforementioned virtual flat surface most only in a nose of cam.

[0028] Drawing 3 shows the schematic diagram of a spin polarization scanning tunneling microscope. The flutter stage 11 is arranged in the vacuum chamber 10, and the jogging stage 13 is attached through the piezoelectric device 12 on it. The flutter stage 11 is controlled by the flutter stage control unit 53, and a piezoelectric device 12 is controlled by piezoelectric-control equipment 52. On the jogging stage 14, the magnetic material 14 symmetrical with evaluation is laid. On the magnetic material 14, the probe 16 is arranged like the case of drawing 2 . A probe 16 is held by the probe electrode holder 15 at a position.

[0029] Coarse positioning of the relative position of the magnetic material 14 to a probe 16 is performed by the flutter stage 11, and highly precise positioning is performed by the piezoelectric device 12. Moreover, a two-dimensional scan is performed by the piezoelectric device 12 by moving a magnetic material 14 to the field inboard.

[0030] Direct current voltage is impressed to a magnetic material 14 from the power supply 51 for bias. The tunnel current which flows between a probe 16 and a magnetic material 14 is amplified by the preamplifier 50, and the amplified electrical signal is inputted into a control unit 54. The power supply 51 for bias, piezoelectric-control equipment 52, and the flutter stage control unit 53 are controlled by the control unit 54.

[0031] The laser beam outputted from the laser oscillation machine 30 is introduced in the vacuum chamber 10 through the Pockels cell 31 and lambda/4 board 32, and carries out incidence to a probe 16. The Pockels cell 31 makes it circle in the polarization shaft of the laser beam outputted from the laser oscillation machine 30. The revolution angle of a polarization shaft changes with the voltage given to the Pockels cell 31 from the power supply 33 for the Pockels cells.

[0032] lambda/4 board 32 changes into the circular polarization of light the laser beam by which the linearly polarized light was carried out. The sense (right-handed rotation or left-handed rotation) of revolution of the circular polarization of light is controlled by the revolution angle of the polarization shaft by the Pockels cell 31. That is, the clockwise rotation circular polarization of light or the anticlockwise rotation circular polarization of light can be generated by adjusting the voltage given to the Pockels cell 31.

[0033] Drawing 4 is drawing which sketched the observation result on the front face of a silicon substrate which the field (111) expressed using the spin polarization scanning tunneling microscope shown in drawing 3 . Setting to 1.0V bias voltage impressed to a silicon substrate, tunnel currents were 1.0nA(s). In addition, incidence of the laser beam to a probe was not performed.

[0034] It turns out that 7x7 structure of the field (111) of a silicon substrate is observed clearly. If incidence of the laser beam is carried out to a probe, the electron by which spin polarization was carried out is excited and it observes, the situation of the magnetic domain of a magnetic material will be able to be evaluated.

[0035] Although this invention was explained in accordance with the example above, this invention is not restricted to these. for example, various change, improvement, combination, etc. are possible -- this contractor -- obvious -- it will be .

[0036]

[Effect of the Invention] As explained above, according to this invention, it can prevent the laser beam which carries out incidence to the probe of a spin polarization scanning tunneling microscope reflecting, and carrying out incidence to the sample for evaluation. For this reason, it becomes possible to suppress disturbance and to perform stable observation.

[Translation done.]

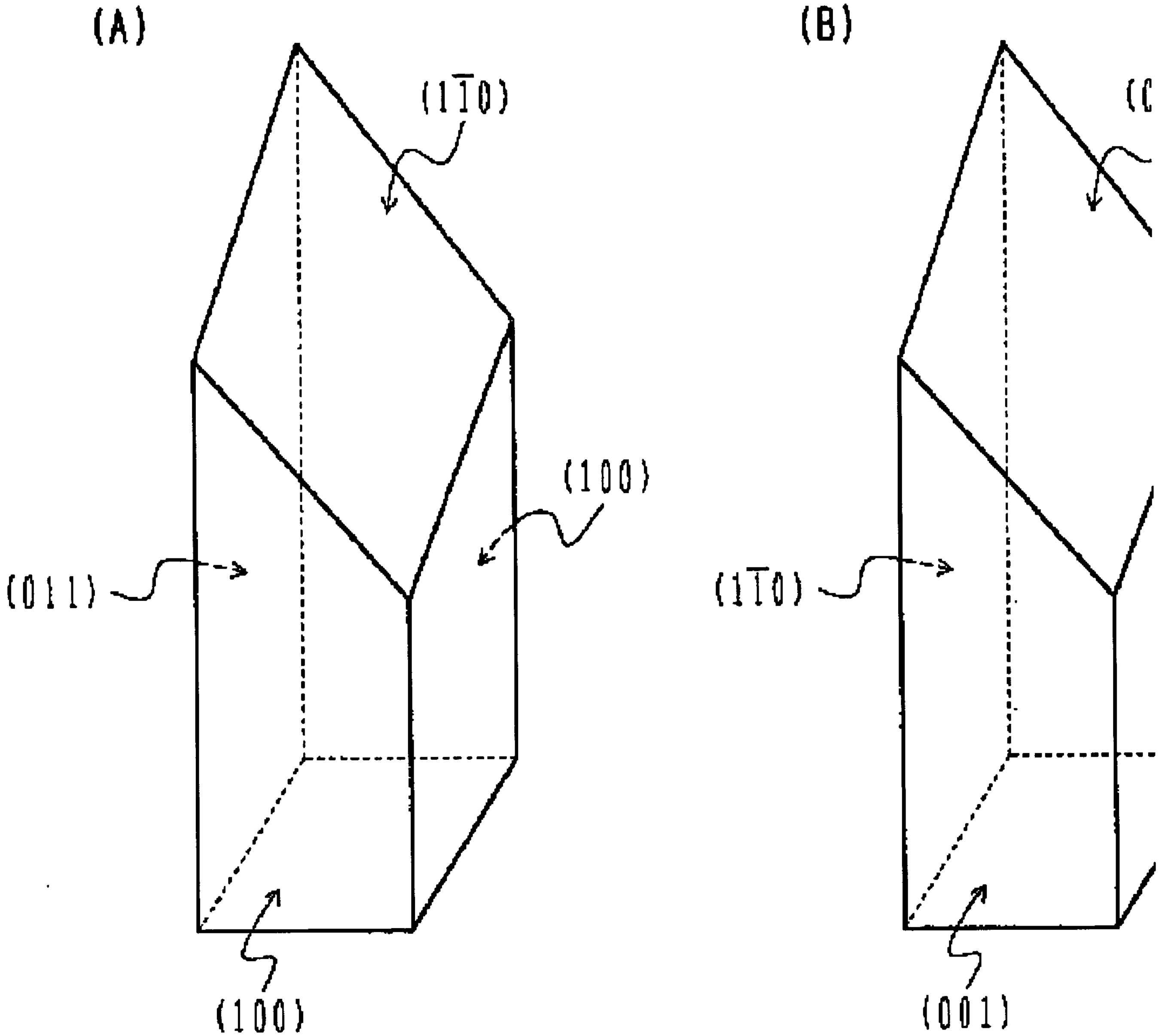
* NOTICES *

CLAIMS

[Claim(s)]
[Claim 1] The probe for spin polarization scanning tunneling microscopes which approaches the aforementioned virtual flat surface most only in the aforementioned nose of cam when the one conical surface has been perpendicularly arranged to this virtual flat surface among two or more conical surfaces which it is formed of the semiconductor material by which the electron which carried out spin polarization by irradiation of a laser beam is excited, use the peak of the conical surface of multiple weight as a nose of cam, and this nose of cam is made to counter the virtual flat surface which has set a certain interval, and demarcate this nose of cam.
[Claim 2] The probe for spin polarization scanning tunneling microscopes according to claim 1 whose conical surfaces to which the aforementioned probe is formed in with a GaAs single crystal, and demarcates the aforementioned peak are the three crystal faces of the three crystal faces, a field (100), a field (011), and (1-10) a field, or (001) a field, a field (1-10), and (0-11) a field.
[Claim 3] The spin polarization scanning tunneling microscope characterized by providing the following. The probe which approaches the aforementioned virtual flat surface most only in the aforementioned nose of cam when the one conical surface has been perpendicularly arranged to this virtual flat surface among two or more conical surfaces which it is formed of the semiconductor material by which the electron which carried out spin polarization by irradiation of a laser beam is excited, use the peak of the conical surface of multiple weight as a nose of cam, and this nose of cam is made to counter the virtual flat surface which has set a certain interval, and demarcate this nose of cam. The sample maintenance base which has the flat sample maintenance side which sets the interval which exists at the nose of cam of the aforementioned probe, and counters. A probe maintenance means to hold the aforementioned probe so that the one conical surface of the aforementioned probe may become perpendicular to the aforementioned sample maintenance side. The laser beam study system for irradiating the laser beam which has an optical axis parallel to the aforementioned sample maintenance side in the aforementioned one conical surface of the aforementioned probe.
[Claim 4] The magnetization information-evaluation method of the magnetic front face characterized by providing the following. It is formed of the semiconductor material by which the electron which carried out spin polarization by irradiation of a laser beam is excited. Use the peak of the conical surface of multiple weight as a nose of cam, and this nose of cam is made to counter the virtual flat surface which has set a certain interval. When the one conical surface has been perpendicularly arranged to this virtual flat surface among two or more conical surfaces which demarcate this nose of cam The process arranged so that the one conical surface may become perpendicular to this measured front face among the conical surfaces which the probe which approaches the aforementioned virtual flat surface most only in the aforementioned nose of cam is made to counter this measured front face of the sample which has a flat measured front face, and demarcate the nose of cam of this probe. The process which irradiates the laser beam which has an optical axis parallel to the aforementioned measured front face in the one aforementioned conical surface. The process which detects the tunnel current which impresses direct current voltage between the aforementioned probe and the aforementioned sample, and flows between this probe and a sample.

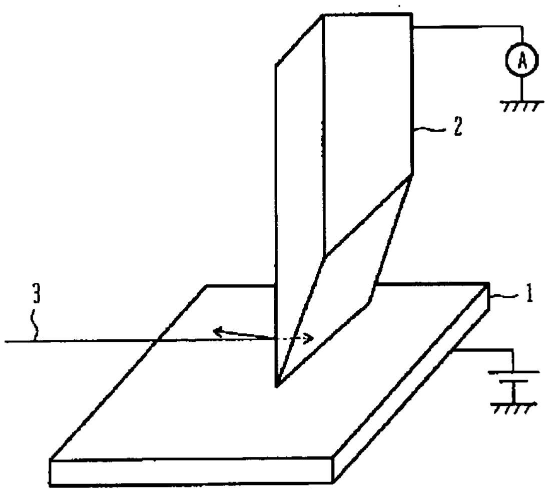
[Translation done.]

スピン偏極走査型トンネル顕微鏡用探針



Drawing selection drawing 2

探針、磁性材料、レーザ光



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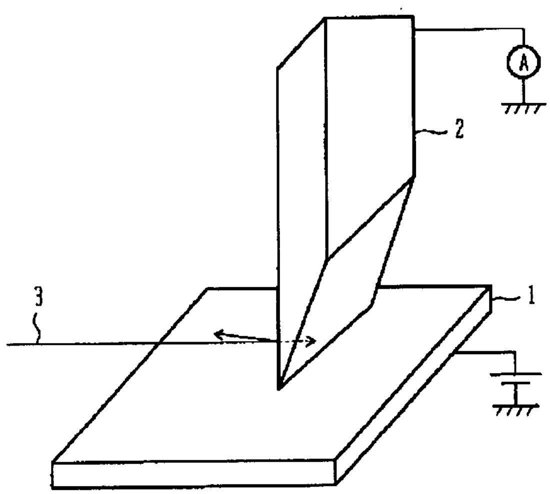
Drawing selection drawing 3

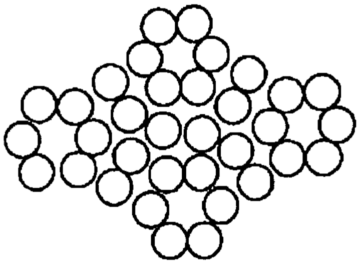
探針、磁性材料、レーザ光



[Translation done.]

Drawing selection drawing 4

シリコン表面の観察結果



[Translation done.]

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審査請求　未請求　請求項の数4　OL　（全 5 頁）

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(71)出願人　000005223
富士通株式会社
神奈川県川崎市中原区上小田中4丁目1番1号

(72)発明者　児玉　宏喜
神奈川県川崎市中原区上小田中4丁目1番1号　富士通株式会社内

(72)発明者　渦巻　拓也
神奈川県川崎市中原区上小田中4丁目1番1号　富士通株式会社内

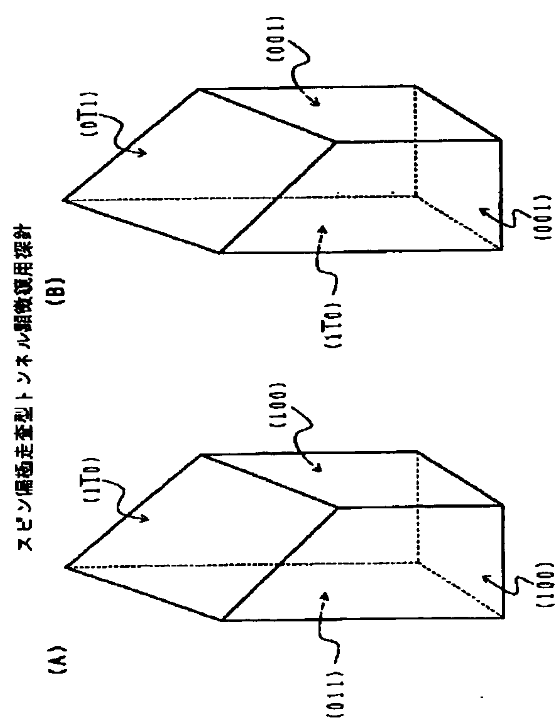
(74)代理人　弁理士　高橋　敬四郎

(54)【発明の名称】　スピン偏極走査型トンネル顕微鏡及びその探針、及び磁化情報評価方法

(57)【要約】

【課題】　測定すべき磁性表面に与える外乱を極力抑制し、高精度の測定が可能なスピン偏極走査型トンネル顕微鏡及びその探針、および磁性表面の磁化情報の評価方法を提供する。

【解決手段】　レーザ光の照射によってスピン偏極した電子が励起される半導体材料により形成されたスピン偏極走査型トンネル顕微鏡用の探針である。この探針は、多角錘の錐面の頂点を先端とし、該先端をある間隔をおいてある仮想平面に対向させ、該先端を画定する複数の錐面のうち1つの錐面を、該仮想平面に対して垂直に配置した場合に、先端のみにおいて仮想平面に最も近接するような形状とされている。



【特許請求の範囲】

【請求項1】　レーザ光の照射によってスピン偏極した電子が励起される半導体材料により形成され、多角錘の錐面の頂点を先端とし、該先端をある間隔をおいてある仮想平面に対向させ、該先端を画定する複数の錐面のうち1つの錐面を、該仮想平面に対して垂直に配置した場合に、前記先端のみにおいて前記仮想平面に最も近接するスピン偏極走査型トンネル顕微鏡用の探針。

【請求項2】　前記探針がＧａＡｓ単結晶により形成され、前記頂点を画定する錐面が、（１００）面、（０１１）面、及び（１－１０）面の3つの結晶面、または（００１）面、（１－１０）面、及び（０－１１）面の3つの結晶面である請求項1に記載のスピン偏極走査型トンネル顕微鏡用の探針。

【請求項3】　レーザ光の照射によってスピン偏極した電子が励起される半導体材料により形成され、多角錘の錐面の頂点を先端とし、該先端をある間隔をおいてある仮想平面に対向させ、該先端を画定する複数の錐面のうち1つの錐面を、該仮想平面に対して垂直に配置した場合に、前記先端のみにおいて前記仮想平面に最も近接する探針と、

前記探針の先端にある間隔をおいて対向する平坦な試料保持面を有する試料保持台と、

前記探針の1つの錐面が前記試料保持面に垂直になるように前記探針を保持する探針保持手段と、

前記探針の前記1つの錐面に、前記試料保持面に平行な光軸を有するレーザ光を照射するためのレーザ光学系とを有するスピン偏極走査型トンネル顕微鏡。

【請求項4】　レーザ光の照射によってスピン偏極した電子が励起される半導体材料により形成され、多角錘の錐面の頂点を先端とし、該先端をある間隔をおいてある仮想平面に対向させ、該先端を画定する複数の錐面のうち1つの錐面を、該仮想平面に対して垂直に配置した場合に、前記先端のみにおいて前記仮想平面に最も近接する探針を、平坦な被測定表面を有する試料の該被測定表面に対向させ、該探針の先端を画定する錐面のうち1つの錐面が該被測定表面に垂直になるように配置する工程と、

前記1つの錐面に、前記被測定表面に平行な光軸を有するレーザ光を照射する工程と、

前記探針と前記試料との間に直流電圧を印加し、該探針と試料間に流れるトンネル電流を検出する工程とを有する磁性表面の磁化情報評価方法。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、スピン偏極走査型トンネル顕微鏡及びその探針、及び磁化情報評価方法に関する。スピン偏極走査型トンネル顕微鏡は、磁性材料の磁化の様子を観察することができ、高い分解能を有する。

【０００２】

【従来の技術】近年、コンピュータの外部記憶用ハードディスク等の磁気記録媒体の記録密度が著しく向上している。その磁気的情報を評価する手法として、磁気力顕微鏡、ビッター法等が知られている。今後さらに記録密度が向上し、1つの磁区が微細になると、これらの評価方法では評価困難になると予測される。

【０００３】微細な磁区を有する磁性表面の磁気的情報を評価する新しい装置として、スピン偏極走査型トンネル顕微鏡が提案されている。スピン偏極走査型トンネル顕微鏡は、スピン偏極した伝導電子を有する探針の先端を磁性材料の表面に微小な間隔で対向させ、探針と磁性材料間にトンネル電流を流し、トンネル電流の大きさで磁気的情報を評価する装置である。

【０００４】このスピン偏極走査型トンネル顕微鏡には、スピン偏極した電子を放出する探針が必要とされる。この探針は、試料に対して極めて接近して配置されるため、試料の磁化情報を変化させないために非磁性体で形成することが好ましい。非磁性体でスピン偏極した電子を放出し得る材料としてＧａＡｓが知られている。

【０００５】Ｇ．ニューネス（G. Nunes）らにより、劈開法を用いて作製したＧａＡｓの探針が報告されている。この探針は、（１００）面のＧａＡｓ基板を、（１００）面と９０°の角度をなす2面で劈開し、（１００）面と2つの劈開面の交点を先端とするものである。

【０００６】このＧａＡｓの探針に、ＧａＡｓのバンドギャップに相当する波長の円偏向レーザ光を照射することにより、価電子帯の電子を励起させ、スピン偏極した伝導電子を得ることができる。伝導電子の偏極度は５０％であり、その偏極方向は照射レーザ光の光軸に対して平行である。偏極の向きは、円偏向レーザ光の旋回方向により決まる。

【０００７】この探針を磁性表面に対向させ、磁性表面に平行な光軸を有するレーザ光を探針に照射すると、探針内に、磁性表面に対して平行なスピン偏極を有する伝導電子が励起される。トンネル電流の大きさは、磁性表面の磁化の向きと探針内の電子のスピン偏極の向きとの関係により変化する。従って、トンネル電流の大きさを測定することにより、磁性表面の磁化の向きに関する情報を得ることができる。

【０００８】磁性表面が、その表面に対して平行に磁化されている場合には、レーザ光の光軸を磁性表面に対して平行にする。

【０００９】

【発明が解決しようとする課題】Ｇ．ニューネスらの探針を磁性表面に対向させると、その先端を画定する3つの錐面のすべてが磁性表面に対して斜めになり、磁性表面側を向くことになる。従って、磁性表面に平行な光軸を有するレーザ光を探針に照射すると、反射光が磁性表面に入射してしまう。磁性表面に入射した反射光が外乱

となり、磁化情報の測定に悪影響を与えると思われる。

【0010】本発明の目的は、測定すべき磁性表面に与える外乱を極力抑制し、高精度の測定が可能なスピン偏極走査型トンネル顕微鏡及びその探針、および磁性表面の磁化情報の評価方法を提供することである。

【0011】

【課題を解決するための手段】本発明の一観点によると、レーザ光の照射によってスピン偏極した電子が励起される半導体材料により形成され、多角錘の錐面の頂点を先端とし、該先端をある間隔をおいてある仮想平面に対向させ、該先端を画定する複数の錐面のうち１つの錐面を、該仮想平面に対して垂直に配置した場合に、前記先端のみにおいて前記仮想平面に最も近接するスピン偏極走査型トンネル顕微鏡用の探針が提供される。

【0012】先端を画定する錐面のうち１つの錐面が、評価対象物の表面に対して垂直になるように配置して測定を行う。評価対象物の表面に対して垂直に配置した錐面に、評価対象物の表面に平行な光軸を有するレーザ光を入射すると、その反射光の光軸も評価対象物の表面に平行になる。このため、反射光が評価対象物に入射しなくなり、反射光の入射による測定への影響を回避することができる。

【0013】本発明の他の観点によると、レーザ光の照射によってスピン偏極した電子が励起される半導体材料により形成され、多角錘の錐面の頂点を先端とし、該先端をある間隔をおいてある仮想平面に対向させ、該先端を画定する複数の錐面のうち１つの錐面を、該仮想平面に対して垂直に配置した場合に、前記先端のみにおいて前記仮想平面に最も近接する探針と、前記探針の先端にある間隔をおいて対向する平坦な試料保持面を有する試料保持台と、前記探針の１つの錐面が前記試料保持面に垂直になるように前記探針を保持する探針保持手段と、前記探針の前記１つの錐面に、前記試料保持面に平行な光軸を有するレーザ光を照射するためのレーザ光学系とを有するスピン偏極走査型トンネル顕微鏡が提供される。

【0014】探針に入射したレーザ光の反射光の光軸が試料保持面に平行になる。このため、反射光が試料保持面に載置した評価対象物に入射しなくなり、反射光の入射による測定への影響を回避することができる。

【0015】本発明の他の観点によると、レーザ光の照射によってスピン偏極した電子が励起される半導体材料により形成され、多角錘の錐面の頂点を先端とし、該先端をある間隔をおいてある仮想平面に対向させ、該先端を画定する複数の錐面のうち１つの錐面を、該仮想平面に対して垂直に配置した場合に、前記先端のみにおいて前記仮想平面に最も近接する探針を、平坦な被測定表面を有する試料の該被測定表面に対向させ、該探針の先端を画定する錐面のうち１つの錐面が該被測定表面に垂直になるように配置する工程と、前記１つの錐面に、前記被測定表面に平行な光軸を有するレーザ光を照射する工程と、前記探針と前記試料との間に直流電圧を印加し、該探針と試料間に流れるトンネル電流を検出する工程とを有する磁性表面の磁化情報評価方法が提供される。

【0016】探針に入射したレーザ光の反射光の光軸が被測定表面に平行であるため、反射光が被測定表面に入射しない。このため、反射光による測定への影響を回避することができる。

【0017】

【発明の実施の形態】図１（Ａ）及び（Ｂ）は、本発明の実施例によるスピン偏極走査型トンネル顕微鏡用探針の斜視図を示す。共にＧａＡｓ単結晶により形成されている。

【0018】図１（Ａ）に示す探針は、（１００）面、（０１１）面、及び（１－１０）面を３つの錐面とする三角錐の頂点を先端とする。（１００）面と（０１１）面とは直交し、（０１１）面と（１－１０）面とは６０°で交わり、（１－１０）面と（１００）面とは４５°で交わる。

【0019】この探針は、例えば（１００）面または（０１１）面が表出したＧａＡｓ基板を劈開して作製することができる。まず、ＧａＡｓ基板を〔１１０〕方向に劈開する。劈開した方向に平行にガラス板を置いてケガキながらさらに劈開し、（１－１０）面で劈開されたＧａＡｓ片を探針とする。

【0020】図１（Ｂ）に示す探針は、（００１）面、（１－１０）面、及び（０－１１）面を３つの錐面とする三角錐の頂点を先端とする。この探針は、（００１）面または（１－１０）面が表出したＧａＡｓ基板を劈開することにより作製できる。図１（Ｂ）に示す探針の形状は、図１（Ａ）に示す探針と同様であり、図１（Ｂ）の探針の（００１）面、（１－１０）面、及び（０－１１）面が、それぞれ図１（Ａ）の探針の（１００）面、（０１１）面、及び（１－１０）面に対応する。

【0021】次に、図２を参照して、図１（Ａ）に示す探針を用いて磁性材料の表面の磁化情報を検出する方法を説明する。なお、図１（Ｂ）に示す探針を用いる場合も同様である。

【0022】平坦な表面を有する磁性材料１の磁性表面に、数オングストローム程度の間隔をおいて探針２の先端を対向させる。このとき、（１００）面及び（０１１）面が磁性材料１の磁性表面に垂直になるように探針２を配置する。例えば磁性表面に垂直な光軸を有するレーザ光３を、（１００）面に入射させる。レーザ光３は、ＧａＡｓのバンドギャップに相当する波長を有する円偏向レーザ光である。

【0023】レーザ光３の一部はＧａＡｓの探針に吸収され、スピン偏極した電子を励起させる。この電子の偏極方向は、レーザ光３の光軸に平行であり、その向きはレーザ光３の旋回方向により決まる。磁性材料１には、

探針２に対して正電圧が印加されており、探針２の先端と磁性材料１との間にトンネル電流が流れる。

【００２４】トンネル電流の大きさは、探針２内のスピン偏極した電子の偏極の向きと磁性材料１の磁化の向きとの相対的な関係により決まる。このため、トンネル電流の大きさを測定することにより、磁性材料１の磁化の向きを評価することができる。また、磁性表面内に関して探針２を走査することにより、磁性表面の磁区の分布の様子を評価することができる。

【００２５】レーザ光３の一部は、探針２の（１００）面により反射する。（１００）面が磁性表面に対して垂直に配置されているため、反射光の光軸も磁性表面に対して平行になり、反射光が磁性材料１に入射しない。このため、反射光による悪影響を排除し、安定した測定が可能になる。

【００２６】なお、レーザ光の入射する面が磁性表面に対して垂直とされていることが好ましいが、反射光が実質的に磁性表面に入射しない程度の傾きであれば、レーザ光の入射する面が磁性表面の法線に対して微小に傾いていてもよい。ここで、「実質的に磁性表面に入射しない」場合とは、反射光が磁性材料の外周よりも外側を通過する場合、及び反射光が磁性材料に入射するが、その入射点が観測点から離れているため観測に影響を与えないような場合を意味する。

【００２７】上記実施例では、ＧａＡｓを用いた探針について説明したが、ＧａＡｓ以外に、レーザ光の照射によってスピン偏極した電子が励起される半導体材料を用いてもよい。この場合、多角錐の錐面の頂点を先端とし、この先端をある間隔をおいてある仮想平面に対向させ、先端を画定する複数の錐面のうち１つの錐面を、仮想平面に対して垂直に配置した場合に、先端のみにおいて前記仮想平面に最も近接するような形状とする。

【００２８】図3は、スピン偏極走査型トンネル顕微鏡の概略図を示す。真空チャンバ１０の中に粗動ステージ１１が配置され、その上に圧電素子１２を介して微動ステージ１３が取り付けられている。粗動ステージ１１は、粗動ステージ制御装置５３により制御され、圧電素子１２は圧電制御装置５２により制御される。微動ステージ１４の上に、評価対称の磁性材料１４が載置される。磁性材料１４の上に、図２の場合と同様に探針１６が配置されている。探針１６は探針ホルダ１５により所定の位置に保持される。

【００２９】粗動ステージ１１により、探針１６に対する磁性材料１４の相対位置の粗い位置決めが行われ、圧電素子１２により、高精度の位置決めが行われる。また、圧電素子１２により、磁性材料１４をその面内方向に移動させることにより、２次元の走査が行われる。

【００３０】磁性材料１４に、バイアス用電源５１から直流電圧が印加される。探針１６と磁性材料１４間に流れるトンネル電流がプリアンプ５０により増幅され、増幅された電気信号が制御装置５４に入力される。バイアス用電源５１、圧電制御装置５２、及び粗動ステージ制御装置５３は、制御装置５４により制御される。

【００３１】レーザ発振器３０から出力されたレーザ光が、ポッケルスセル３１、λ／４板３２を通って真空チャンバ１０内に導入され、探針１６に入射する。ポッケルスセル３１は、レーザ発振器３０から出力されたレーザ光の偏光軸を旋回させる。偏光軸の旋回角は、ポッケルスセル用電源３３からポッケルスセル３１に与えられる電圧により変化する。

【００３２】λ／４板３２は、直線偏光されたレーザ光を円偏光に変換する。円偏光の旋回の向き（右回りまたは左回り）は、ポッケルスセル３１による偏光軸の旋回角により制御される。すなわち、ポッケルスセル３１に与える電圧を調節することにより、右旋回円偏光または左旋回円偏光を発生させることができる。

【００３３】図4は、図3に示すスピン偏極走査型トンネル顕微鏡を用いて（１１１）面の表出したシリコン基板表面の観察結果をスケッチした図である。シリコン基板に印加するバイアス電圧を１．０Ｖとし、トンネル電流は１．０ｎＡであった。なお、探針へのレーザ光の入射は行わなかった。

【００３４】シリコン基板の（１１１）面の7×7構造が明瞭に観察されていることがわかる。探針にレーザ光を入射し、スピン偏極された電子を励起させて観察すれば、磁性材料の磁区の様子を評価することができるであろう。

【００３５】以上実施例に沿って本発明を説明したが、本発明はこれらに制限されるものではない。例えば、種々の変更、改良、組み合わせ等が可能なことは当業者に自明であろう。

【００３６】

【発明の効果】以上説明したように、本発明によれば、スピン偏極走査型トンネル顕微鏡の探針に入射するレーザ光が反射して、評価対象の試料に入射することを防止できる。このため、外乱を抑制し、安定した観察を行うことが可能になる。

【図面の簡単な説明】

【図１】本発明の実施例によるスピン偏極走査型トンネル顕微鏡用探針の斜視図である。

【図２】探針、磁性材料、レーザ光の相対位置関係を示すためのこれらの斜視図である。

【図３】スピン偏極走査型トンネル顕微鏡の概略図である。

【図４】スピン偏極走査型トンネル顕微鏡を用いたシリコン表面の観察結果をスケッチした図である。

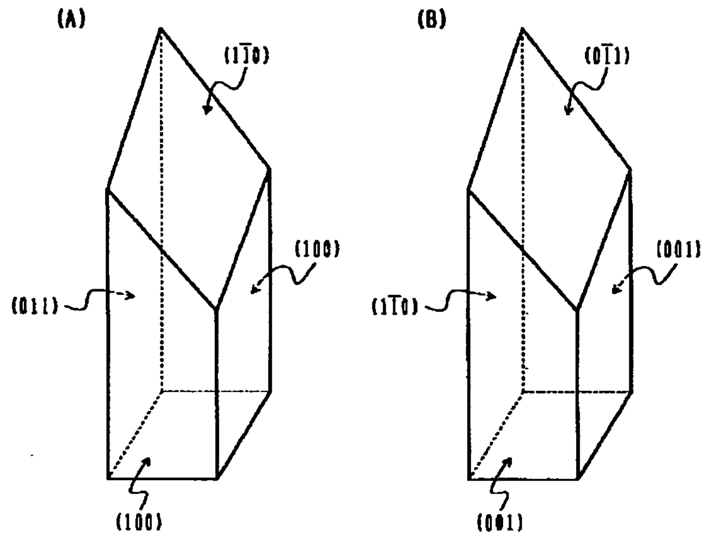
【符号の説明】

１　磁性材料
２　探針
３　レーザ光

10 真空チャンバ
11 粗動ステージ
12 圧電素子
13 微動ステージ
14 磁性材料
15 探針ホルダ
16 探針
30 レーザ発振器
31 ポッケルスセル
32 λ／4板
33 ポッケルスセル用電源
50 プリアンプ
51 バイアス用電源
52 圧電制御装置
53 粗動ステージ制御装置
54 制御装置

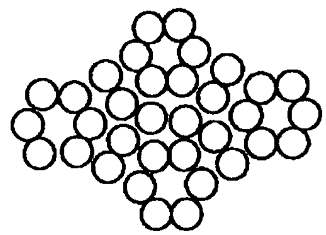
【図1】

スピン偏極走査型トンネル顕微鏡用探針



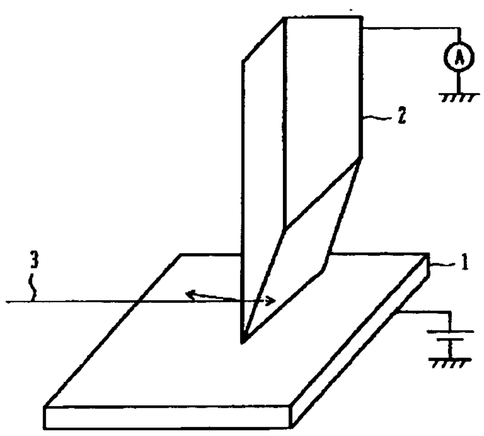
【図4】

シリコン表面の観察結果



【図2】

探針、磁性材料、レーザ光



【図3】

スピン偏極走査型トンネル顕微鏡